Technologies de rupture pour futures charges utiles de télécommunications

Technology disruptions in future communication payloads

Jean-Didier Gayrard
Alcatel Space
26, avenue J-F Champollion BP 1187
31037 Toulouse, France

Résumé

Le marché des télécommunications par satellite sera modelé par quatre principales tendances: la démocratisation, la régionalisation, la numérisation et l'utilisation des très hautes fréquences. Pour faire face à la demande économique et technique du marché et pour concurrencer les réseaux terrestres, opérateurs et fabricants doivent faire évoluer leurs satellites. Cette évolution peut prendre deux voies: le gigantisme ou l'adaptation. Ces deux voies demandent aux charges utiles de passer d'un niveau de complexité passé et présent, qui était bien adapté à la diffusion de télévision et à la téléphonie en bandes C et Ku, à un niveau de complexité bien supérieur. Toute technologie innovante et de rupture est la bienvenue. Un premier cortège de technologies de rupture vient des technologies optiques et optroniques. La rapide expansion de ces technologies dans les réseaux terrestres pourrait aussi bénéficier aux charges utiles des satellites à large bande. On en attend plus de bande passante, des réductions de masse, de la flexibilité et des traitements sophistiqués. Un deuxième ensemble de rupture viendra du froid: l'électronique refroidie, la supraconductivité et la cryogénie. Les supraconducteurs à haute température (HTS) permettent la conception de récepteurs à très faible bruit, des filtres compacts et sans pertes. Les supraconducteurs à basse température (LTS) qui sont utilisés dans les circuits logiques RSFQ donne la puissance de calcul requise pour le traitement du signal à très large bande et la numérisation directe des signaux micro-ondes. Le traitement numérique du signal apportera aussi une rupture dans les satellites de télécommunications. Les technologies numériques vont améliorer tous les traitements: formation de faisceaux, filtrage, routage, linéarisation, démodulation… Les processeurs numériques seront plus flexibles, plus performants, reconfigurables ou actualisables en vol (software radio). Les micro-systèmes (MEMS) devraient aussi jouer un premier rôle dans la conception des futures charges utiles..

Abstract

The market of satellite telecommunications will be shaped by four main trends: democratization, regionalization, digitalization and the use of higher frequency bands. To cope with the economical and technical demands of the market and to compete with the terrestrial networks, operators and manufacturers shall upgrade theirs satellites. The evolution should take two ways: gigantism or adaptation. Both way will requires satellite payloads to evolve from past and present level of complexity that was mainly suited for TV broadcasting and telephone trunking in the Ku and C bands, to a new and higher level of complexity. Anyway innovative and disruptive technologies will be welcome. A first procession of disruptive technologies comes from optical and optoelectronical technologies. The rapid expansion of these techniques in terabit terrestrial networks could also benefit satellite wideband payloads. Large bandwidth, mass savings, flexibility and advanced processing are expected. A second set of disruptions could come from the cold: chill electronics, superconductivity and cryogenics. High temperature superconductors (HTS) allow very low noise front ends, compact and lossless filters. Low temperature superconductors (LTS) used in RSFQ logic integrated circuits give the required computing power for wideband signal processing and analog to digital flash conversion of microwave signals. Digital signal processing will bring also disruption in communication satellites. Digital techniques will enhance every payload processing: beam forming, filtering, routing, linearization, demodulation... Digitized onboard processors will be more flexible, better performing and reconfigurable or upgradable (software radio). Micro-systems (MEMS) should also play leading role in the design of the next payloads.

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1. Evolution of the satellite business

The role of satellite in the telecommunication world is evolving. Communication satellites were mainly used for TV broadcasting, for hauling data or telephone trunks and for networking VSAT. The preferred frequency bands were the C and Ku bands. It is still mostly the case today, but new trends in the market will change the nature of the communication satellites.

The first trend is the democratization of satellite communications. It started with DTH (Direct-To-Home) which has accustomed everyone to buy "ground station" (the dish and its set-top box) in supermarkets and to install it on the balcony or roof of his house. Satellite communications is becoming a mass market, especially in foreseen broadband applications (Internet by satellite). Broadband satellites should offer high-speed connections to millions of low price terminals. The present generation of satellites is not really suited for broadband missions involving millions of small and power limited terminals. A new family of satellites shall be designed to cope with this unusual requirement.

The second trend is digitalization. Analog transmissions will soon disappear, digital communications and packet transportation protocols will prevail in satellite communications. Present satellites were designed for bent pipe analog transmissions. Onboard regeneration and packet switching suit better digital packet transmissions and shall gain the trust of the operators.

A third trend is the race to more bandwidth and higher frequencies. Mobile Satellite Service extends in S-band, beyond the L-band originally in use. Fixed and Broadcast Satellite Services will span in the Ka-band and later in the V/Q band far beyond the presently used C and Ku bands. The recourse to cellular coverage with frequency re-use is part of this trend. Cellular coverage allows re-using allocated frequencies and increasing significantly the overall bandwidth of the system. Such coverage provides better communication performances but highly increases the complexity of onboard routing and prevents easy broadcasting. Next satellite generation should handle this higher complexity.

The last trend is regionalization of the service. International institutional operators (Intelsat, Eutelsat, Inmarsat…) have been privatized and lose their institutional role of international public services. Private operators are either local operators or global operators resulting from the merging of local operators. Both types of operators are aiming regional or national markets. This geographic segmentation of the market is also due to economical, cultural, linguistic, fiscal and legal reasons. Economical reasons are linked to the level of purchasing power of the consumers. Legal or cultural reasons such as copyright rules, linguistic homogeneity, legal obligation[1], tax and license for terminal use… are segmenting the market. The impacts of this trend should be also taken into account.

2. Evolution of the satellite definition

Obviously these trends should have impacts on the evolution of the definition of the next satellite generation, especially the broadband satellites in Ka-band. Two other factors will also constraint the evolution of the satellites: cost reduction and flexibility. Cost reduction is a continuous effort of the satellite industry to keep its competitiveness. Flexibility aims at giving operators more reactivity to market changes.

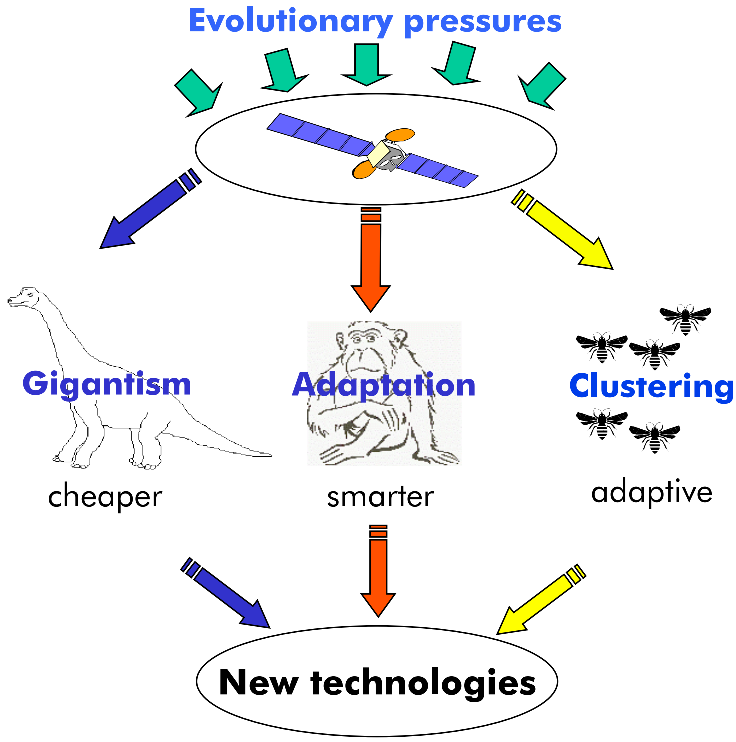
The three main options in evolution to adapt to new environment constraints are gigantism (big like dinosaurs), adaptive (smart and versatile like primates) and modularity (numerous and specialized like ants). Satellites could evolve according to these three axes. In all cases, new disruptive technologies are required.

[1] For example, the Satellite Home Viewer Extension and Reauthorization Act in USA

Keeping and bettering the competitiveness of satellite essentially motivates the trend to gigantism. It is about providing capacity (repeaters) at the lowest cost. It results in more and more powerful and large payloads that include lots of lightweight, power saving and cheap to build equipment. Platform price, launch service and operation costs became marginal. Giant satellite is cost effective but lacks flexibility.

The trend to adaptation is motivated by the need to have satellite that either adapt to market changes or provide high value added services. It is about providing performing and flexible capacity. It results in payloads with enhanced performances and large onboard processing. Flexibility is seldom synonymous with cheap.

The modularity results in taking into account both factors: flexible (complex) and cheap (large) capacity. The payload is distributed among several small satellites working together thanks to intersatellite links. Satellites are designed, build and commissioned according to market evolution.



3. Optical technologies

Optics and photonics bring unusual but attractive and performing solutions for implementing payload functions. Optical techniques could be viable solutions to replace and enhance existing techniques in mid term. In the long term, optical techniques will be the only solution to create new functions of the satellites to come.

In mid term, there are three applications where optical technologies could apply: optical gigabit backplane connections, microwave transportation and routing, telemetry and command systems.

Optical gigabit backplanes allow high rate connections between Integrated Circuits (IC), Printed Circuit Boards (PCB) and units in onboard digital processors and large mass memories. The interconnections between PCB are becoming a limiting factor to the progression of miniaturization and processing speed in digital electronic units. The clock frequency and the number of interfaces and pins of VLSI ASIC and μprocessor increase continuously. PCB connectors potentially available for space applications are staying limited in pin number and bandwidth. These limitations are direct consequence of physical constraints such as pin spacing, insertion force, alignment… Serial gigabit optical links is able to increase

the bandwidth and reduce the number of connections between ASIC, PCB or units. The advantages of this technique are a high density of interconnection, full electromagnetic compatibility (cross-talk, galvanic isolation…), high data rate (> 2 Gbps per link), mass saving, backplane standardization and genericity.

Optic fibers could replace coaxial harness in communication payloads. Associated with MOEMS (Micro-Opto-Electro-Mechanical System), it will enhance the routing capability of broadband payloads. Frequency reference distribution is also a promising application of microwave photonics. Generally speaking, the main advantages are lightweight and very low loss of optical fibers compared to copper wires, very large bandwidth, galvanic isolation and full electromagnetic compatibility (EMC/EMI), new functions routing function like WDM (Wavelength Division Multiplexing). The poor noise figure and the low power handling of lasers, diodes and photo-detectors prevent the use of optical techniques neither in low noise receiving sections nor in high power output sections of a satellite repeater.

Communication payloads with a high degree of reconfigurability and a large number of units will require lots of acquisition and command signals to control and monitor the payload. Optic fibers and wireless infrared links are attractive choices to build the onboard telemetry and command system for the next generation of platform. Optical fiber is the perfect physical layer for avionics buses (OBDH or 1553). Wavelength multiplexing (1300/1550 nm) allows bi-directional links on the same fiber. Optical fibers have a large bandwidth, spare mass and prevent any EMC problem. Another attractive alternative for reducing the harness is a wireless short-range communication system between onboard equipment such as infrared optical wireless links.

4. Technologies from the cold

A second set of disruption could come from the cold: chill electronics and superconductor electronics.

Chill electronics is only the simple cooling of semiconductors to improve their performances. The losses and noise factor of analog circuits decrease, the speed of digital circuits (ASIC) can be enhanced. The reliability of the circuits should also improve. An active or passive cooling at a low temperature range (-30 to -50 °C) of digital onboard processor will be beneficial in terms of clock speed and reliability and will ultimately simplify redundancy architecture. Chilling a regular C-MOS ASIC would increase by +50% its operating speed. In a first approximation, it can be associated to a 30% saving in the mass and volume budget. The cooling of the input filter and low noise amplifier (LNA) decrease the input losses and noise factor (0.01 dB/K reduction), leading to the improvement of the merit figure (G/T) of the satellite.

Cryonic electronics encompass two domains: the High Temperature Superconductors (HTS) around 70 to 80 K and Low Temperature Superconductors (LTS) between 4 and 8 K. The introduction of superconductor technologies is not a "simple upgrade" of existing microwave or digital units but has some significant impacts on the spacecraft design. A superconductor system includes not only the superconductor devices and theirs electronic drivers but also the cryocoolers to generate the low temperature and the thermal management system to keep it.

HTS materials and thin film deposition allow designing very performing microwave functions, mainly very low noise receiver, compact and lossless filters, ultra-low phase noise oscillators. This technology brings solutions to miniaturize the RF front end and to improve the G/T of active antenna. Superconductive input filters are smaller and have less losses and better selectivity (Q factor). The HTS material enables planar technology for filter banks instead of resonator cavity filters. Lowloss and high Q factor give a significant miniaturization factor (5 to 10), particularly in C-band. More, the pattering of planar structures is more reproducible than mechanical cavity filter assemblies and allows trimming-less filters that will decrease the production duration and give an economical advantage.

LTS superconductors that are used in RSFQ (Rapid Single Flux Quantum) logic integrated circuits give the required computing power for wideband signal processing and analog to digital flash conversion of microwave signals. RSFQ is the most recent family of superconductor digital devices. It offers a considerably higher speed (up to 800 GHz for simple niobium-based digital circuits) and much lower power dissipation (of the order of 10-18 Joule per bit around of 5 K). The operating temperature is around 5 K for the more mature process. This technology permits to envisage the full digital processing of microwave signals, associated with the concept of software radio. The digital RF front end becomes almost independent of waveform, channel number and bandwidth. The equipment becomes more standard with a specific user adaptation with software and finally a cost reduction.

In summary chill and superconductive technologies can dramatically improve the performances of payloads, decrease their mass and volume. The price to pay is the cost associated with the cooling system, the cryo-packaging and the new architecture of the thermal management of the platform.

5. The digital revolution

Digital technology should dramatically change satellite design and utilization. Digital signal processing could apply to virtually all functions: beam forming, filtering, routing, demodulation and switching, linearization…

The continuous improvement of digital microelectronics technologies and digital signal processing techniques [according with the Moore's law, the number of transistors on a chip doubles every 17 months, the processing capacity of a digital chip increases by 390 % in two years, and the power dissipated by 47 %] allows contemplating a full digitalization of broadband payloads and especially multi-beam-forming. The computing burden that is required for processing large bandwidth would pose major technological challenges. But advantages of digital implementation are numerous and could tip the balance in favor of satellite in future multimedia networks.

6. Micro-systems

A Micro-ElectroMechanical Systems (MEMS) is a miniaturized system which is build by microelectronics processes and allows the combination of mechanical, optical, fluidic and electrical functions. It is also possible to integrate these MEMS devices with more traditional electronic components, allowing among other things, the fabrication of complete microscopic systems.

This last decade, the domain of MEMS has grown rapidly and has recently found applications in radiofrequency and microwave. MEMS technology applied to microwave switching gathers both advantages of electro-mechanical devices (low insertion loss, high isolation, no power consumption in steady states) and those of microelectronics (high compactness, reproducibility, mass manufacturing process, low-cost). Micro-machining allows designing new parts: variable capacitors, high-Q inductors, high-Q resonators and resonant cavity filters.

So, combining switches and micro-machined parts open the way to very compact and performing microwave assemblies: controllable phase-shifters, switch matrices, variable oscillators…. up to the active skin of reflect array antenna.

7. Conclusion

Compared with other areas of Research and Development, R&D in space communication is mainly characterized by costly and lengthy developments for a small number of satellites. This sets a real problem regarding the return on R&D investment.

New trends in the satellite market as well as the persistent quest for cost reduction and flexibility will trigger and stimulate an evolution in communication payloads. Finally, after decades of rigid transparent and narrow band applications for professionals, the communication satellite market is about to enter a new age of flexible, regenerative and wide band applications for all. Disruptive technologies are more than ever longed for. But, this will demand a tremendous effort in R&D for satellite manufacturers and operators and this, just at a time when operators are more and more hesitant to invest in new markets.

The road leading to development, control and qualification of new technologies is long and expensive. Specialization, collaboration and cooperation among the space electronics manufacturer seem requisite. Support from national and European agencies seems also essential.

May, 15th 2005

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